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**OFFICE OF ENGINEERING AND TECHNOLOGY**
**SEEKS COMMENT ON MEASUREMENT REPORT OF DTV RECEIVER**
**INTERFERENCE REJECTION CAPABILITIES**

**ET Docket No. 04-186**

**Comments due: April 30,2007**
**Reply comments due: May 15,2007**

On October 12, 2006, the Commission adopted a First Report and Order and Further Notice of Proposed Rule Making in ET Docket Nos. 04-186 and 02-380 to permit the operation of new low power devices in the broadcast television spectrum on channels/frequencies that are not being used for authorized services. In that action, the Commission also stated that its Laboratory was conducting a testing program to quantify the interference rejection capabilities of DTV receivers and intends to issue a report of the results of these measurements by March 2007.

The Commission's Laboratory recently completed this testing program and released a report of the measurement results:

- The testing program examined the out-of-channel interference rejection performance of a representative sample of eight DTV receivers with fifth generation tuners that were available in 2005 and 2006.
- A total of 2055 individual measurements were performed on these receivers.
- Each test involved feeding a desired signal to the television under test and injecting an interfering signal on a different channel or combination of channels. The different tests varied the level of the desired signal and interfering signal(s).
- The results show the interference rejection capabilities of the DTV receivers that were tested.
- The information from these tests is generally useful to analyze the potential for interference to DTV broadcasts from out-of-band signals. However this information is only one element of many that must be examined in evaluating the possibilities for operation of new low power devices in unused portions of the TV broadcast bands.

This report is available through the Commission's Electronic Comment Filing System (ECFS) at http://www.fcc.gov/cgb/ecfs/. It is also available on the Commission's web site at www.fcc.gov/oet/.

Interested parties may file comments on this report no later than April 30, 2007. Reply comments are due no later than May 15,2007. All filings should reference ET Docket No. 04-186.

Comments may be filed using: (1) the Commission's Electronic Comment Filing System (ECFS), (2) the Federal Government's eRulemaking Portal, or (3) paper copies. ***See Electronic Filing of Documents in Rulemaking Proceedings,*** 63 FR 24121 (1998).

- Electronic Filers: Comments may be filed electronically using the Internet by accessing the ECFS: http://www.fcc.gov/cgb/ecfs/ or the Federal eRulemaking Portal: http://www.regulations.gov. Filers should follow the instructions provided on the website for submitting comments.

- For ECFS filers, if multiple docket or rulemaking numbers appear in the caption of this proceeding, filers must transmit one electronic copy of the comments for each docket or rulemaking number referenced in the caption. In completing the transmittal screen, filers should include their full name, U.S. Postal Service mailing address, and the applicable docket or rulemaking number. Parties may also submit an electronic comment by Internet e-mail. To get filing instructions, filers should send an e-mail to ecfs@fcc.gov, and include the following words in the body of the message, "get form." A sample form and directions will be sent in response.

- Paper Filers: Parties who choose to file by paper must file an original and four copies of each filing. If more than one docket or rulemaking number appears in the caption of this proceeding, filers must submit two additional copies for each additional docket or rulemaking number.

Filings can be sent by hand or messenger delivery, by commercial overnight courier, or by first-class or overnight U.S. Postal Service mail (although we continue to experience delays in receiving U.S. Postal Service mail). All filings must be addressed to the Commission's Secretary, Office of the Secretary, Federal Communications Commission.

- The Commission's contractor will receive hand-delivered or messenger-delivered paper filings for the Commission's Secretary at 236 Massachusetts Avenue, NE, Suite 110, Washington, DC 20002. The filing hours at this location are 8:00 a.m. to 7:00 p.m. All hand deliveries must be held together with rubber bands or fasteners. Any envelopes must be. disposed of before entering the building.

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For questions concerning the DTV receiver measurement report, please contact Mr. Steve Martin, (301) 362-3052, e-mail Steve.Martin@fcc.gov. For further information concerning this public notice, please contact Mr. Hugh L. Van Tuyl, (202) 418-7506, e-mail Hugh.VanTuyl@fcc.gov.

Chief, Office of Engineering and Technology.

-OET-

# Interference Rejection Thresholds of Consumer Digital Television Receivers Available in 2005 and 2006

**March 30,2007**

**Technical Research Branch**
**Laboratory Division**
**Office of Engineering and Technology**
**Federal Communications Commission**

**OET Report**
**FCC/OET 07-TR-1003**

**Prepared by:**
**Stephen R. Martin**

# ACKNOWLEDGEMENTS

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# EXECUTIVE SUMMARY

This report presents the results of two categories of tests performed on consumer digital television receivers to assess their vulnerability to out-of-channel interference:

- Tests of tuner type; and
- Interference rejection threshold tests.

The first category of test identifies the type of tuner (*e.g.*, single-conversion versus double-conversion) in consumer DTV receivers. A knowledge of tuner type aids in identifying the channel offsets at which a TV receiver is likely to be susceptible to interference. The second type of test measures the ability of DTV receivers to reject interference from signals in TV channels other than the one to which the TV is tuned.

The test results are intended to support assessments of interference to DTV reception from:

- non-TV use of locally-unused spectrum within the TV broadcast spectrum, which is also often termed "white-space" use;
- non-TV use of spectrum adjacent to or near TV broadcast spectrum (*e.g.*, the TV channel 52 to 67 spectrum that will be auctioned for other uses); and,
- other DTV stations.

The results also enable evaluation of the degree to which consumer DTV receivers comply with the voluntary standards contained in the receiver standards document, "ATSC Recommended Practice: Receiver Performance Guidelines"'

It should he noted that this study characterizes susceptibility of consumer DTVs to interference in terms of signal and interference levels appearing ***at the antenna input terminal*** of the receiver. Assessments of potential for interference to DTV reception will require additional analysis involving specific protection scenarios? propagation modeling, and antenna modeling, which are beyond the scope of the study.

## *TUNER TYPE TESTS*

Measurements on the "Grand Alliance" prototype DTV receiver provided the basis for establishing interference protection criteria for the DTV channel allotment process. That receiver used a double-conversion tuner. Consumer DTV receivers often use single-conversion tuners, which can be more susceptible to interference at certain channel spacings than a double-conversion tuner. Most of the analog TV taboos that limited allotments of channels at certain spacings in a given local area were the result of interference vulnerabilities associated with single-conversion tuners.

Tests were performed on thirty consumer DTV receivers to determine their tuner types. All were found to have single-conversion tuners. While the use of single-conversion tuners implies the possibility of interference susceptibilities at the same frequency offsets as those experienced by analog TV, it should be noted that such interference vulnerabilities are lower for digital TV than for analog TV because the ATSC DTV system **is** inherently more resistant to interference than the NTSC analog system.

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[*] Advanced Television Systems Committee, "ATSC Recoinmended Practice: Receiver Performance Guidelines", ***<ATSC Receiver Guidelines>***, ATSC Doc. A/74, 17 June 2004.

[†] In this context, a protection scenario refers to a set of conditions that may be pan of the analytic process of setting protection limits. The conditions might include such factors as the distance from the interfering device to the antenna of the DTV receiver and the attenuation of any intervening walls.

## *INTERFERENCE REJECTION TESTS*

The out-of-channel interference rejection threshold of consumer digital television (DTV) receivers was measured by supplying an ATSC 8-VSB* signal (the *desired* signal), along with one or two ***undesired*** signals. to the antenna terminal of a DTV receiver and then adjusting the level of the undesired signal(s) to the point at which picture degradation begins to he observed—a point known **as** the threshold of visibility (TOV) of degradation. In such testing, the DTV receiver is tuned to the channel number of the desired signal. The undesired signal (the potential interferer) is placed on another channel, either above or below the desired channel.

We refer to the desired signal power at the input to the DTV receiver as D and the undesired power when adjusted to the threshold (TOV) as U. It is traditional to express interference rejection performance in terms of the ratio D/U. When DIU is expressed in decibels (dB), it is typically a negative number for out-of-channel interference; that is, the undesired signal level is greater than the desired signal at TOV. Low values (*i.e.*, large negative numbers) represent good rejection performance; high values (small negative numbers) represent high *susceptibility* to interference. D/U ratios measured for this report ranged from below **-74** dB to -20 dB. Results in this report are presented both as D/U ratios and as threshold values of the undesired signal power U in order to meet the needs or preferences of different analysts.

Most of the interference rejection tests were performed on eight consumer DTV receivers that were on the market in 2005 and 2006. The eight receivers were identified **as** having fifth-generation multipath-handling capability Limited tests were also performed on two earlier-generation receivers.

It should he noted that the out-of-channel interference tests for this report were performed using a test setup that suppressed leakage of the undesired signal into the desired channel to a sufficient degree to make spectral leakage effects negligible. Thus, the first-adjacent channel tests do not include the effects of spectral splatter representative of a DTV transmitter—an effect which drives the first-adjacent channel protection ratios used for DTV channel allotments.

## *INTERFERENCE FROM ONE UNDESIRED SIGNAL*

### Channel Selection

All tests for this report were performed in the UHF TV band. For the bulk of the testing, the TV was tuned to a desired signal on channel **30** (designated as channel **"N"**), and the undesired signal was sequenced through channels N-1 through N-16 and N+1 through N+16. The earliest testing in the program was performed with the desired signal on channel 51 and the undesired signal placed on channels N+1 through N+16.

The measurements on channel 51 generally matched those on channel **30** within about 4 dB—and in most instances much closer than that.

### Undesired Signals

All tests were performed using undesired signals that were continuous, as opposed to occurring in bursts (as might he typical for packet-based communications).

* 8-level Vestigial Side Band (8-VSB) is the over-the-air digital television (DTV) transmission format specified **by** the Advanced Television Systems Committee's(ATSC) Digital Television Standard (**A/53**) and adopted by the FCC as the **U.S.** standard for terrestrial DTV broadcasting.

### *Signal Type*

For most tests the undesired signal was either an 8-VSB DTV signal or a white Gaussian noise signal that had been bandlimited to match the 3-dB width of the 8-VSB signal. The selection between these two signal types was driven by equipment availability and spectrum shape requirements.[1]

A smaller number of tests were performed to compare the interference effects of three signal types:

- The 8-VSB DTV signal;
- The Gaussian noise signal bandlimited to match the 8-VSB signal width (at the 3-dB points);
- An OFDM signal (DVB-H) that was about 5-MHz wide.

The results show that the DTV receivers are more vulnerable to out-of-channel interference from the Gaussian noise and OFDM signals than from the 8-VSB DTV signal by an amount just over 1 dB.

### *Signal Bandwidth*

For most tests, the undesired signal filled most of the 6-MHz width of a TV channel. Tests were also performed on one TV using a narrower signal—Gaussian noise bandlimited to a 3-dB bandwidth of 1 MHz. DIU ratios with this reduced-bandwidth signal were comparable to those for the wider undesired signals except in channel offsets where significant narrowband interference effects occurred. One prominent such effect occurred with the interference on channel N+7, where an interference susceptibility peak was observable on **7** of the **8** DTV receivers that were tested with the broader signals. Tests with the narrow signal showed that the N+7 interference effect is narrowly centered at the local oscillator frequency of the receiver **(44** MHz above the center of the tuned channel).

### *Signal Levels*

**If** DIU ratios were constant with changes in desired signal level, measurements at a single desired signal level would be sufficient to characterize the interference susceptibility of a TV receiver at a given channel offset; however, the tests showed that threshold DIU ratios vary with signal level, and do so in ways that vary among the different channel offsets on different TVs. The nature of the variation also changes with signal level. As a result, tests were performed at three desired signal levels specified by the ATSC (-28, -53, and **-68** dBm) as well as one additional signal level, $D_{MIN}$ + 3 dB, where $\mathbf{D_{MIN}}$ refers to the receiver-specific desired signal level at TOV in the absence of interference (essentially, the minimum signal level at which a given DTV receiver can operate). In addition, modeling was performed to extend the results down to $D_{MIN}$ + 1 dB.

## **Cliff Effect**

The digital television broadcast system can achieve flawless picture reception under interference conditions (D/U ratios) that would produce an unusable picture for analog broadcast TV; however, once an undesired signal reaches a level at which picture impairments become visible on a DTV receiver, the picture degrades extremely rapidly with further increases in undesired signal level. This characteristic of DTV receiver performance is known as the “cliff effect”. The interference rejection thresholds of the tested receivers exhibited a strong “cliff effect”. In most cases, increasing interference level about 1 dB above the TOV level, at which picture impairments are first observed, caused complete loss of the TV picture.

[1] An 8-VSB signal was used for the first tests performed under this program (those on channel 51) because it nearly filled the **6-MHz** width of a TV channel and it exhibited steep rolloff at the band edges—an essential characteristic for adjacent-channel interference tests. After failure of that 8-VSB source, tests (on channel **30)** were performed using the bandlimited Gaussian noise source. Because the band-edge rolloff of that signal was not sufficiently steep to permit interference measurements on first-adjacent channels, those tests were postponed until procurement of a new 8-VSB signal source (after repair of the previous source was found to be impossible). All tests involving two interferers made use of bandlimited Gaussian noise as the second source.

## Reiection Performance

No receiver appeared to fully achieve the ATSC recommended guidelines for interference rejection performance—guidelines that are less stringent than the receiver performance assumptions on which current DTV interference protection criteria are based.' After taking into account differences between the Gaussian-noise interferer used for most of the tests and the 8-VSB interferer specified by the ATSC, the best-performing receiver appears to fail the guidelines at only one channel offset, and there by only 1 dB. A second receiver failed to meet the voluntary guidelines by 1 to **2** dB at two channel offsets. The remaining five receivers failed to meet the guidelines at two to 16 channel offsets; the worst failure for each of those receivers ranged from about 8 to **24** dB.

The rejection performance of the receivers is summarized by plots in the final chapter of this report. The following observations apply to the results.

- In terms of absolute signal levels that can cause interference, the DTV receivers are at their most vulnerable when operating at low desired signal levels.
- At low desired signal levels the DTV receivers are *us* susceptible to interference from the second-adjacent channels (N-2 and N+2) as from first-adjacent channels (N-1 and N+1). In terms of worst and second-worst performance, the receivers are actually *more* susceptible to interference from second-adjacent channels than from first-adjacent channels. (This contradicts the assumptions of OET-69[†] and the ATSC Receiver Guidelines.)
- The receivers tend to he more susceptible to interference from N+2, N+1, N-1, N-2, N-3, N-4, and sometimes N-6 than from the mixer image channel offsets of N+14 and N+15.
- At moderate desired signal levels, the receivers exhibit relatively high susceptibility to interference from channel N+7. This interference threshold is nearly constant in terms of absolute power of the undesired signal necessary to cause interference at different levels of desired signals. At lower desired signal levels, other channel offsets become more vulnerable.

# *INTERFERENCE FROM IM3-GENERATING PAIRS OF UNDESIRED SIGNALS*

Pairs of undesired signals placed on channels N+K and N+2K, where K is a positive or negative integer, create an opportunity for ***third-order intermodulation (IM3)*** occurring in the DTV tuner to create spectral products that fall in the desired channel N. These spectral products can interfere with TV reception. Though the D/U ratios associated with paired-signal IM3 effects tend to decrease as the desired signal decreases, the test results show that IM3 can constitute a dominant interference mechanism even at desired signal levels very near the minimum signal threshold for the TV ($D_{MIN}$).

Measurements of interference thresholds were performed with equal-powered undesired signals on N+K/N+2K combinations for eight TVs on channel 30 and seven TVs on channel 51. Tests were performed for K = -5 to **5** when N was 30 and for K = **1** to 8 when N was 51. In both sets of tests, the desired signal levels were -68 dBm and -53 dBm. Not all measured cases produced interference effects that were sufficiently higher than the single-channel effects to allow isolation of the 1M3 effects. For those that did, a third-order intercept point (IP3) was computed.

The 1P3 data was used to predict paired-signal IM3 interference effects at lower *desired* signal levels than the measurements and at *unequal undesired* signal levels—predictions that were tested by measuring two receivers using unequal undesired signals. The results show that when such signal pairs occur, they

* The ATSC provides recommended guidelines for DTV receiver performance in its document, "ATSC Recommended Practice: Receiver Performance Guidelines", ATSC Doc. A/74, 17 June 2004.

[†] "Longley-Rice Methodology for Evaluating TV Coverage and Interference", Office of Engineering and Technology (OET) Bulletin No. 69, <OET-69>, Federal Communications Commission, 6 February 2004.

represent the dominant interference mechanism for channel offsets from about N+4 to N+16 (with the exception of the mixer image at N+14 and N+15) and from about **N-5** to N-IO. For spacings close to channel N (*e.g.*, N+/-1 and N+/-2), the paired-signal effects appear less likely to dominate — at least if the pair has equal power levels. No paired signal measurements were performed beyond N+16 and N-IO, ***so*** it is not know how far out the effect continues; however, the effect is seen to diminish with increasing channel offset from the desired channel.

Paired signals at IM3-generating spacings have the potential to create even greater interference susceptibilities if an existing undesired signal on one of the IM3-generating channels (*e.g.*, a nearby DTV broadcast station when the receiver is tuned to a more distant station) exceeds the measured equal-power-level threshold for paired signals. In such a case, the presence of that signal can greatly increase susceptibility to interference on the other channel of the IM3-generating pair. This situation generally creates the greatest vulnerabilities when the stronger undesired signal is on channel N+K and it exceeds the equal-power paired-signal threshold in that case, the receiver susceptibility to interference on the N+2K channel increases by twice the N+K signal excess above the equal-power threshold (in dB).

The ATSC Receiver Guidelines document (A/74) provides no recommended performance levels for rejection of paired-signal interference.

# CHAPTER 1
# INTRODUCTION

This report presents the results of laboratory tests of consumer digital television (DTV) receivers to determine:

- Tuner type (*e.g.*, single conversion); and
- UHF our-of-channel interference rejection thresholds at the antenna input terminal of the receiver

The term, "out-of-channel" interference, as used in this report, includes any interference occurring outside of the 6-MHz width of the TV channel to which the receiver is tuned. Thus, it includes: first-adjacent channels; "taboo" channels associated with analog TV (*i.e.*, TV channels more than one channel away from the desired channel at specific channel spacings associated with interference vulnerabilities of analog TV); other TV channels; and interference from sources outside of spectrum allocated to broadcast TV.

The tuner type tests were performed on 30 consumer DTV receivers—29 of which were on the market in mid-to-late 2005 and the other of which was procured in 2006. 28 of the receivers had been subjected to other terrestrial reception performance testing during an earlier program conducted as part of the Commission's compliance with the Satellite Home Viewer Extension and Reauthorization Act of 2004 (SHVERA).[*]

Extensive interference rejection tests were performed on eight of the receivers. Limited interference rejection testing was performed on two other receivers as part of the tuner type tests.

## BACKGROUND

The ability of television receivers to operate in the presence of interference is an important factor in determining whether consumers can receive TV broadcast service. It is generally recognized that the ATSC DTV system (also known as 8-VSB)[†] used for terrestrial broadcast digital TV in the United States is less susceptible *to* interference than the NTSC analog TV system that it is replacing. This increased robustness has enabled a relaxation of the "taboo" rules that govem channel spacings of broadcast television stations in a local area—allowing part of the spectrum formerly assigned for broadcast TV use (UHF channels *52* through 69) to be made available for other **uses** after the completion of the DTV transition.

The Federal Communications Commission's (FCC) rules that are intended to prevent interference to broadcast DTV reception' are based on the interference rejection performance of the so-called "Grand Alliance" DTV prototype receiver. These rules define the interference protection afforded to broadcast TV stations, and receiver manufacturers are expected to consider the signal protection ratios in the rules when designing their TV receiver products. While the prototype DTV receiver used a double-conversion tuner configuration, some authors have surmised that many modem consumer DTVs employ single-conversion tuners that may he more susceptible to out-of-channel interference at some frequencies than a

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[*] Stephen R. Martin, "Tests **of** ATSC 8-VSB Reception Performance of Consumer Digital Television Receivers Available in 2005", Report FCC/OET TR 05-1017, **<*SHVERA Study*>**, November **2,** 2005. (www.fcc.gov/oet/info/documents/reports/TR-05-1017-ATSC-reception-testing.pdf)

[†] 8-level Vestigial Side Band (8-VSB) is the over-the-air digital television (DTV) transmission format specifiedby the Advanced Television Systems Committee's **(ATSC)** Digital Television Standard (A/53) and adopted by the FCC as the U.S. standard for terrestrial DTV broadcasting.

[‡] See 47 C.F.R. section 73.623(d)

double-conversion tuner.[*][†] In addition, other design differences between the "Grand Alliance" prototype DTV receiver and today's consumer receivers could potentially affect the degree of a receiver's ability to reject out-of-channel interference.

Interference can be broadly divided into two categories:

- Co-channel interference; and,
- Out-of-channel interference.

Co-channel interference results from undesired emissions at frequencies within the channel that a television receiver is currently attempting to receive. Out-of-channel interference results from emissions occurring in a frequency range outside that of the TV channel to which the receiver is tuned. Out-of-channel emissions may come from another TV broadcast or a non-TV source.

## <u>Co-Channel Interference Reiection</u>

Tests conducted by the FCC Laboratory in *2005* on 28 consumer DTV receivers demonstrated that the receivers differ very little in their immunity to broadband <u>*cn-channel*</u> interference. In those tests, receivers were found to produce pictures that were free of visual errors when the TV signal power exceeded broadband interference power within the same TV channel by a threshold ranging from 14.9 to 15.8 dB, with the median threshold being 15.3dB.[‡] These results closely match the 15.2 dB threshold of the Grand Alliance receiver.[§]

The small variation of co-channel interference rejection performance among the receivers and the close match to the older Grand Alliance results are in line with the expectation that co-channel interference rejection threshold is determined primarily by the structure of the ATSC DTV signal format adopted by the FCC.

## <u>Out-of-Channel Interference Reiection</u>

Unlike co-channel interference rejection, out-of-channel interference rejection of a DTV receiver is expected to depend heavily on receiver characteristics, such as tuner selectivity, tuner image performance, automatic gain control (AGC) implementation, and tuner overload characteristics.

Because of this dependence on receiver characteristics and because modem consumer DTV receivers may differ substantially in design from the Grand Alliance receiver, new measurements are required to characterize out-of-channel interference rejection of today's DTV receivers.

# *OBJECTIVES*

The DTV receiver measurements described in this report are intended to support assessments of interference to DTV reception from:

- non-TV use of locally-unused spectrum within the TV broadcast spectrum, which is also often termed "white-space" use;
- non-TV use of spectrum adjacent to or near TV broadcast spectrum (*e.g.*, the TV channel 52 to 67 spectrum that will be auctioned for other uses); and,
- other DTV stations.

[*] Charles W. Rhodes, "The Challenge of Channel Election, *TY Technology.com*, January 19, 2005. (<u>http://www.tvtechnology.com/features/digital_tv/Features_Rhodes-01.19.05.shtml</u>)

[†] Oded Bendov and others, "Planning Factors for Fixed and Portable DTTV Reception", *IEEE **Transactions** On Broadcasting*, Vol. 50, No. 3, September **2004.**

[‡] Martin, <SHVERA Study>, 2005, chapter 3.

[§] Federal Communications Commission Advisory Committee on Advanced Television Service, "Final Technical Report". Oct 31, 1995, p.19.

The results also enable evaluation of the degree to which consumer DTV receivers comply with the voluntary standards contained in the receiver standards document, “ATSC Recommended Practice: Receiver Performance Guidelines”[*]

A device that transmits radio energy on an otherwise unused TV channel (or in spectrum adjacent to a TV band) can interfere with DTV reception in one of two ways, or in a combination of the two:
(1) The radio energy it creates in its intended hand of operation may impact the DTV receiver through various receiver vulnerabilities caused by nonlinearities in the receiver, mixer images, or other mechanisms;
(2) The device may unintentionally “splatter” enough energy into the channel to which the DTV receiver is tuned to interfere with TV operation.
The first of these ways **is** true out-of-channel interference; the second **is** a form of co-channel interference. Given that either of these factors—or a combination thereof—could determine interference rejection performance, one way to test DTV receivers would he to subject them to simulated interferers that contain both an intended emission on a channel outside of the desired channel and spectral splatter into the desired channel. The resulting interference performance measurements would reflect the combination of the two interference effects. However, given that there is debate within the technical community regarding both the intended emissions and the out-of-hand (*e.g.*, spurious) emissions for devices operating in the “white spaces”, we believe it is appropriate to deal with these two types of interference separately. As was stated in the previous section, co-channel interference is relatively well understood and relatively constant among ATSC DTV receivers compared to out-of-channel interference; consequently, we chose to measure only true out-of-channel interference in this study. As such, we applied filtering to the outputs of out-of-channel signal sources used in the tests in order to reduce their spectral splatter into the desired channel to negligible levels.

It should he noted that this study characterizes susceptibility of consumer DTVs to interference in terms of signal and interference levels appearing ***at the antenna input terminal*** of the receiver. Assessments of potential for interference to DTV reception will require additional analysis involving specific protection scenarios: propagation modeling, and antenna modeling, which are beyond the scope of the study

## *MEASUREMENT PROGRAM*

The tests were performed on subsets of the 28 DTV receivers that had been tested in 2005 in support of the *Satellite* ***Home*** **Viewer** ***Extension and Reauthorization Act of 2004*** *(SHVERA)*.[‡] An additional receiver that was received too late for inclusion in that study, **as** well **as** one that was purchased in 2006, were also tested, bringing the total to 30 receivers. Five of the **30** receivers were set top DTV tuners. The remaining 25 were DTVs with integrated digital tuners.

The measurement program described here consisted broadly of two parts: (1) tuner type characterization; (2) interference rejection threshold tests.

Tuner type characterization was intended to identify tuner topology used in consumer DTV receivers. The first phase of these tests involved searching for a local oscillator (LO) signal at the antenna inputs of each of the 30 DTV receivers while switching between two channels. The tests demonstrated that at least

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[*] Advanced Television Systems Committee, “ATSC Recommended Practice: Receiver Performance Guidelines”. <ATSC Receiver Guidelines>, **ATSC** Doc. A/74, 17 June 2004.

[†] In this context, a protection scenario refers to a set of conditions that may be part of the analytic process of setting protection limits. The conditions might include such factors as the distance from the interfering device to the antenna of the DTV receiver and the attenuation of any intervening walls.

[‡] Martin, <SHVERA Study>, 2005.

28 of the 30 receivers use single-conversion tuners with an intermediate frequency (IF) of 44 MHz. For the two receivers that produced inconclusive results in the LO tests. interference rejection tests were used to identify any interference susceptibilities that would he a "signature" of single-conversion receivers with 44-MHz IF. Those two receivers were also determined to use single-conversion tuners.

Interference rejection threshold testing consists of measuring the maximum signal level at which an undesired (*i.e.*, interfering) signal can be injected into the TV receiver's antenna input without adversely affecting TV reception of a "desired" signal. The behavior of DTV signal reception in this regard differs considerably from that of analog TV reception. The DTV broadcast system can achieve flawless picture reception under interference conditions that would produce an unusable picture for analog broadcast TV; however, once an undesired signal reaches a level at which picture impairments become visible on a DTV receiver, the picture degrades extremely rapidly with further increases in undesired signal level — typically going from barely perceptible picture impairments to complete **loss** of picture with a span of about I dB. Similar degradation of analog reception occurs over a span as large as 30 dB, a difference that emphasizes the importance of these measurements for DTV.

Because of the number of variables involved in interference rejection testing, measurements were performed on only ten DTV receivers. Seven of these included one of each brand selected from among receivers exhibiting "fifth-generation'' DTV demodulator performance in the SHVERA Study. An eighth TV was procured in 2006. The remaining two, on which only limited interference rejection testing was performed, were the two receivers for which the LO tests were inconclusive.

Initial focus of the work reported herein was on the immunity of the receivers to interference from future radio services that will operate in the channel *52* to 67 spectrum after completion of the DTV transition. Consequently, the initial tests were performed with the receivers tuned to channel 5I and interference placed on channels ***52*** through 67. Subsequent measurements, focused on the white-space use of the TV spectrum, were performed with the receivers tuned to channel 30 — near the center of the UHF core TV spectrum — with interferers placed both above and below channel 30.

Interfering sources used for most of the testing included an ATSC 8-VSB DTV signal and a pseudo-random Gaussian noise signal bandlimited to the same spectral width as a DTV signal (5.38 MHz, 3-dB width). Except for the small pilot tone of the DTV signal, both signals exhibit noise-like signal characteristics and relatively flat spectra similar to those of most modem communication systems using digital modulation. **A** few tests were performed using an OFDM signal and using a narrower width Gaussian noise signal, for comparison.

In accordance with standard industry practice, the interference rejection threshold of the receiver is expressed as the ratio of desired signal power to undesired signal power (***D/U ratio***) at the threshold of visibility (TOV) of degradation of the TV picture. For a few interference mechanisms, the threshold D/U ratio remains constant as the desired signal level **is** varied except at low signal levels, hut many other mechanisms are non-linear, resulting in variable DIU ratios that are further affected by the receiver's automatic gain control **(AGC)** in a way that **is** not predictable without a detailed knowledge of the design of the each receiver; consequently, measurements were performed at multiple desired signal power levels.

Interference rejection thresholds are also a function of the frequency spacing between the desired TV signal and the undesired interfering signal. Single-conversion TV receivers are known to exhibit interference susceptibilities up to 90 MHz (15 TV channel widths) from the desired TV channel;' consequently, measurements with single interferers were performed at various frequency spacings within, and just beyond, this range.

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' The mixer image for a single-conversion TV Nner **is** centered 88 MHz above the center frequency of the desired channel. It occupies portions of channels N+14 and N+15, where N **is** the desired channel.

In addition, pairs of interfering signals at particular spacings can he expected to create interference through non-linear effects in a TV tuner; consequently, some tests were performed using pairs of interferers spaced at intervals that could cause third-order intermodulation distortion to fall in the desired channel.

## *OVERVIEW*

Chapter 2 of this report describes the scope of the test program and the general testing approach

Chapter 3 describes the tests performed to determine DTV tuner type (single conversion versus double conversion or other types) and the results of those tests.

**All** remaining chapters deal with interference rejection performance of the DTV receivers, as described below.

Chapter **4** describes the test methodology employed for interference testing, the performance of the test setup, and some reference values for rejection performance from other documents.

Chapter **5** presents the results of rejection performance measurements on eight DTV receivers tuned to channel 30 (N=30) for a single undesired signal placed on each of the channels from N-1 to N-16 and N+I to N+I 6 The undesired signal was an 8-VSB signal for channels N-1 and N+1 and a white Gaussian noise signal bandlimited to match the 3-dB width of an 8-VSB signal for all other channels. The desired signal power levels for these tests were **-28** dBm, -53 dBm, -68 dBm, and $D_{MIN}$ +3 dB, where $\mathbf{D_{MIN}}$ refers to the individually measured threshold for each receiver when operated without interference.

Chapter 6 presents results of rejection performance measurements on seven DTV receivers (a subset of the eight) tuned to channel **5**1 **(N–51)** for a single undesired 8-VSB signal placed on each of the channels from N+1 to N+16. The desired signal power levels for these tests were -28 dBm, -53 dBm, and -68 dBm.

Chapter 7 presents the results of measurements of the differences in interference effects of four undesired signal types:

- White Gaussian noise bandlimited to the 3-dB width of an 8-VSB source;
- 8-VSB;
- DVB-H—an orthogonal frequency division multiplexing (OFDM) signal—set for a 5-MHz channel width; and
- White Gaussian noise bandlimited to a 3-dB width of 1 MHz.

The chapter also presents the effects of signal quality differences of **two** different 8-VSB signal generators that served as the desired source.

Chapter 8 presents a theoretical framework that aids in interpreting and extending the out-of-channel interference measurements.

Chapter 9 presents the results of interference rejection measurements performed using equal-power pairs of undesired signals spaced so as to place third-order intermodulation (IM3) products in the desired channel. The tests were performed on eight DTV receivers tuned to channel 30 and seven DTVs tuned to channel **5**1. Undesired signals were placed at channel pairs N+K/N+2K for K = -1 through -5 and +1 through +5 for channel 30 and K = 1 through 8 for channel 51. The undesired sources were the same as those described for Chapters **5** and 6. Values of a third-order intercept parameter (IP3) were estimated based on some of the measurements.

Chapter 10 presents interference rejection measurements on two receivers (one N+K/N+2K channel offset pair for each) using a pair of undesired signals of ***unequal*** amplitudes. It also presents a model that is then used to make predictions regarding interference rejection performance of the other tested DTV receivers for unequal, paired undesired signals. The model makes use of measurements from Chapters **5** and 9.

Chapter 11 presents measurements of rejection performance for one DTV receiver over a wide, finely-stepped desired-signal amplitude range. The tests included single interferers, as well as paired interferers spaced to place IM3 products in the desired signal channel. The measurements provide insight into the behavior of interference susceptibilities including their nonlinearities and the effects of receiver AGC.

Chapter 12 extrapolates the channel-30, single-channel interference rejection measurements from Chapter **5 of** this report to a lower desired signal level, $D_{MIN}$ + 1 dB. It also employs measured data from Chapter 11 to evaluate the extrapolation method.

Chapter **13** combines the single-channel rejection performance *measurements* of the eight DTV receivers on channel **30** from Chapter **5** (at D = **-28** dBm, **-53** dBm, **-68** dBm, and $D_{MIN}$ **+** 3 dB) with the *extrapolations* of Chapter **12** (to D = $D_{MIN}$ + 1 dB) to present combined results.

Chapter 14 presents the results of tests and analyses performed to validate the test methodology and test setup used **for** the measurements in this report (Direct measurements of test setup performance are shown in Chapter 4.)

Chapter 15 presents the summary and conclusions. It also includes new graphs that integrate the results of some of the other chapters in terms of median, 2nd worst, and worst performance among the eight receivers.

# CHAPTER 2
# SCOPE AND APPROACH

## *SCOPE OF TESTING*

Two types of tests were performed on DTV receivers in the measurement program reported herein: (1) frequency measurements of tuner local oscillator (LO) signals leaking out of the TV receiver antenna terminal: **(2)** signal levels of desired and undesired signals at the TV receiver antenna port with the undesired signal set to the threshold of visibility (TOV) of degradation of the received TV picture.

Measurements of the LO, where possible, serve to characterize the type of receiver (single or double conversion) and intermediate frequency (IF) for single conversion receivers.

The signal level measurements at TOV quantify the immunity of the receiver to out-of-channel interference and also can be used to aid in characterizing receiver type when LO leakage is not measurable. These results are expressed as interference rejection ratio threshold—the ratio of desired signal power to undesired (interfering) signal power (D/U ratio) at TOV.

### Interfering Signal Types

The objectives of the testing were to generate data that could be used to assess potential interference to DTV by future devices operating in TV white spaces, future services operating in channels 52 through 67 after the completion of the DTV transition, and other DTV signals. Ideally, measurements would have been performed using each potential type of interfering signal; however, white-space devices and signals to be transmitted in channels 52 through 67 are not fully defined, and, even if representative devices bad been available, the number of tests would have been prohibitive.

Most modem digital communications systems produce signals that are somewhat noise-like. The spectra are often flat over most of their channel width; they have relatively high peak-to-average ratios and peak levels that are random, rather than fixed—as in the case of most analog transmissions. **A** growing number of digital systems are using orthogonal-frequency-division-multiplexing (OFDM) signals. Both the 8-VSB DTV signal used for broadcast DTV in the United States and OFDM signals share these noise-like, flat-spectrum characteristics (except for the 8-VSB pilot).

We initially expected that bandlimited white noise, 8-VSB DTV signals, and OFDM signals of equal bandwidths would be likely to exhibit similar interference effects on DTV reception. (Later, testing described in Chapter **7** caused a small adjustment to this expectation.) Initial single-interferer testing was performed using an 8-VSB DTV signal as the interferer and TV receivers tuned to channel 51. For tests with pairs of interferers to create intermodulation distortion within the TV receivers, a Gaussian noise generator- bandl limited to the same 3-dB width **as** an 8-VSB signal—was used as the second interferer because an additional 8-VSB source was not available. The measurements on channel 51 were terminated after failure of the 8-VSB source that had been used as an interferer.

**All** further tests were performed with the TV receivers tuned to channel 30 because of the change in focus of the project from interference effects of services in channel 52 through 69 to interference effects of white-space devices, which would be limited to VHF and core UHF channels. Channel 30 was selected for testing because it is a locally-unused channel near the center of the core UHF band.

The testing with TV receivers tuned **to** channel **30** was initiated using a Gaussian noise generator—bandlimited to the 3-dB width of an 8-VSB signal—as the interferer, because the only available 8-VSB source was being used to generate the desired signal. For intermodulation tests, two such signal sources were used **as** interferers. The bandlimited Gaussian noise sources did not exhibit a band-edge rolloff steep enough to support tests of interference on first-adjacent-channels (*i.e.*, N-1 or N+1 when the TV is tuned to channel N); consequently, first adjacent channel tests were postponed until a new 8-VSB DTV signal source was procured. That source, which arrived late in the test program, was then used for all tests **on** first-adjacent channels for N=30.

A limited number of tests were performed to compare the interference results of four interferer types:
(1) 8-VSB DTV signal;
(2) Gaussian noise bandlimited to match the 3-dB width of an 8-VSB signal;
(3) an OFDM DVB-H signal; and
(4) Gaussian noise bandlimited to a 3-dB width of 1 MHz.
The OFDM DVB-H signal was generated using a commercial software package for a vector signal generator with parameters set for a **2k** OFDM signal with 5-MHz channel width and **64** QAM modulation

Figures 2-1 and 2-2 show measured spectra of the four interferers at equal total power levels. Table 2-1 shows bandwidths of each signal.

| Signal | 3 dB Bandwidth (MHz) | 20-dB Bandwidth (MHz) |
|---|---|---|
| 8-VSB (Bandwidths, neglecting pilot) | 5.38 | 5.90 |
| Gaussian noise (8-VSB width) | 5.38 | 6.32 |
| Gaussian noise (1-MHz width) | 1.00 | 1.18 |
| OFDM DVB-H | 4.78 | 4.80 |

## Desired Signal Levels

The ATSC specifies guidelines for interference rejection performance of DTV receivers at three desired signal levels: -68 dBm, -53 dBm, and **-28** dBm, which they designate as "weak", "moderate", and "strong", respectively. Our initial intent was to test only at these three signal levels; however, after tests demonstrated that D/U rejection ratios are by no means constant as a function of desired signal power, a decision was made to extend the measurements to a lower level that was receiver dependent.

The motivation for the tests at lower desired signal levels, near $D_{MIN}$, can be seen in Figure 2-3 and Table 2-2, both of which show the relationship of desired signal levels to broadcast coverage area with flat terrain.[*] The computations are based on the Egli propagation model,[†] which has propagation loss proportional to the fourth power of distance. If we view the outer boundary of a broadcast station's coverage area to be determined by the point at which consistent reception is just barely possible with a given receiver and antenna system (*i.e.*, no signal margin remains after normal amplitude variations of the signal due to fading), then the signal margin will be less than 1 dB in the outer 11 percent of the coverage area. Similarly, the outer 29 percent of the coverage area has **less** than 3 dB of margin, and fully **84**

[*] The actual pattern of TV desired signals can differ significantly from the flat terrain model due to the variability in terrain and other geographic features that are present in a local area; consequently, terrain-dependent models are normally used for coverage area calculations. The simpler model used here is intended only to provide some insight regarding signal excess.
[†] J. Egli. "Radiowave propagation above **40** Mc over irregular terrain", Proceedings of the IRE, Vol. 45, Oct. 1957, pp.1383-1391.

percent of the coverage area would experience lower signal levels than the ATSC-designated "weak" signal level of -68 dBm (where the excess signal is nominally 16 dB).*

Given the above analysis and the increased vulnerability to interference when the desired signal levels are low, a decision was made to extend the results — through both measurement and extrapolation — to signal levels close to the DTV receiver thresholds. Specifically, the desired signal threshold ($D_{MIN}$) for each TV was measured in the absence of interference. Interference rejection tests were then conducted at a desired signal level 3 dB higher than this threshold—*i.e.*, at $D = D_{MIN} + 3$ dB. In addition, analytical work was performed to extrapolate the test results down to a desired signal level of $D_{MIN} + 1$ dB.

***Table 2-2.*** Relationship *Between* **Excess Signal** and Coverage Area

| Excess Signal (dB) | $R/R_{MAX}$ | Percentage of Coverage Area Having Less Excess Signal Than That Shown |
|---|---|---|
| 0 | 1 | 0% |
| 1 | **0.94** | 11% |
| 3 | 0.84 | **29%** |
| **10** | 0.56 | 68% |
| 16 | **0.40** | **84%** |

## TV Receiver Samples

A total of 30 receivers were available for this test program. One TV was procured in 2006 and 29 were provided by the manufacturers for the Congressionally-mandated 2005 SHVERA Study (though only 28 had arrived in time to he included in that study). The 29 receivers from the SHVERA Study had been selected to be representative of consumer DTV receivers that were on the market in the summer of 2005. Five of the receivers were set top boxes and 25, including the one procured in 2006, were DTVs with built-in digital ATSC tuners. The DTV receivers comprise 16 brand names and a wide range of prices, sizes, and display technologies, **as** shown in Table 2-3.

**All** 30 receivers were tested to determine tuner type. Local oscillator sensing was sufficient to identify **all** but two of the receivers **as** having single-conversion tuners with 44-MHz IF. The remaining two were subjected to limited interference rejection performance tests to look for signatures of single-conversion tuners. Such signatures were found in both receivers.

Because of the complexity of interference testing, only eight of the receivers were selected for interference rejection tests (beyond the limited testing on two receivers mentioned in the preceding paragraph). The selection process was **as** follows. Of the 28 receivers that had been tested in the SHVERA Study, only ten had been found to exhibit "upper tier" (or "fifth generation") multipath performance. Those ten, which were among the more recently introduced receivers used for the SHVERA Study', along with the receiver procured in 2006 (which **also** exhibited "upper tier" multipath performance), were taken to be representative of the new generation receiver technology. The eleven

* We note that these percentages assume that the same TV antenna system (*e.g.*, a high gain antenna on a IO-meter mast and a downlead having a given loss) is used throughout the coverage area. **If** closer-in TV viewers choose less extensive antenna systems (lower gain, shorter mast, or indoor location), those customers may experience low signal excess even if far inside the maximum coverage range.

† Martin, <SHVERA Study>, **2005,** chapter 6.

comprised eight brands of receivers. All were DTVs (*i.e.*, none were set top boxes).[*] One receiver of each brand from among the eleven—a total of eight receivers—was selected for interference rejection testing. The eight included receivers from all price ranges.

Specific receivers are identified in both this report and the SHVERA Study by two-character codes—a letter followed by a number—in order to avoid revealing specific brands or models. Additional information regarding the samples can be found in the **SHVERA** Study.[†]

*Table 2-3.* DTV ***Receiver Samples***

| Sample Type | Number of Samples: LO Tests | Number of Samples: Rejection Tests | Display Size | Display Aspect Ratio | Display Technology[A] |
|---|---|---|---|---|---|
| **Set-Top Box (STB)** | 5 | 0 | N/A | N/A | N/A |
| **DTV with Integrated ATSC Digital Tuner[B]:** | | | | | |
| • $370 - $1000 | 7 | 2 | 26" – 36" | 4:3 or 16:9 | Direct-View CRT |
| • $1001 - $2000 | 8 | 2+1[C] | 26" – 52" | 16:9 | Direct-View LCD, Plasma, CRT Rear Proiection. DLP Rear Projection, LCD Rear Projection |
| • $2001 - $4200 | 10 | 4+1[C] | 32 – 62 | 16:9 | Direct-View LCD, Plasma, DLP Rear Projection, LCD Rear Projection |
| **TOTAL** | *30* | **8+2[C]** | | | |

Note:
*A* – Display Technologies
- CRJ = cafhode ray tube (conventional picture tube)
- *DLP* = digital *light* processing
- *LCD* = liquid crysfal display

*B* -- Prices shown are market prices *in* August or September 2005.
C – *1st* number represents receivers selected for test based *on* having *"upper-tier" DTV* demodulator performance; *2nd* number represents receivers tested *to* characterize receiver type where *LO* tests were inconclusive.

## *INTERFERENCE REJECTION TESTING APPROACH*

### <u>TV Channel Selection</u>

Initial tests were performed with **TV** receivers tuned to channel *5*1 and interferers placed on channels *52* through 67 in order to provide data on the receivers' ability to reject interference from services that may operate in the spectrum of channels *52* through 67 after the **DTV** transition is complete.

Subsequent testing was performed with TVs tuned to channel 30, to represent performance near the middle of the UHF core band.

[*] The absence of **a** set top box among the receivers is consistent with the fact that all set top boxes that were identified for inclusion **in** the SHVERA Study had been introduced to the market in or before November 2004—**a** date that **was** probably too early to have included "fifth generation" DTV reception technology.
[†] Martin, <SHVERA Study>, **2005.**